GLOBAL AND LOCAL STATISTICS CONTROLLED NOISE

REDUCTION SYSTEM

By:

Peng Lin

and

Yeong-Taeg Kim

GLOBAL AND LOCAL STATISTICS CONTROLLED NOISE REDUCTION SYSTEM

By

Peng Lin

and

Yeong-Taeg Kim

Field of the Invention

The present invention relates generally to video image processing, and more particularly to noise reduction in video images.

Background of the Invention

Video images are often corrupted by noise during the video image acquisition or transmission process. In order to improve the visual appearance of such images, an effective filtering technique is often required to reduce the noise level therein. Traditional noise reduction techniques mainly involve applying a linear filter such as an averaging filter to all of the pixels in a video frame ("image"). While this reduces noise level in the image, such a linear filtering technique also indiscriminately blurs edges in the image.

In order to prevent image edge blurring, a noise reduction filter must be adaptive to local structures, such as edges, in the image. One such adaptive technique is known as directional filtering. Directional filtering

5   attempts to avoid image blurring by adapting linear filtering to image edge directions in such a way that the filter utilized is always applied along the edge direction not across the edge direction.

10   FIG.1 shows a block diagram of an example directional filter 100. At each image pixel, first the 2-D local variance is computed by a local variance calculator 120 for a small window. Then, the 1-D local variances are computed along the horizontal, vertical, diagonal from upper left to

15   lower right, and diagonal from upper right to lower left directions within the same window of pixels. To determine the edge direction, the 2-D variance is compared with a predetermined threshold in an edge direction detector block 140. If the 2-D variance is less than the threshold, then

20   no edge is present at the pixel, and the pixel is considered having "no direction". If the 2-D variance is greater than the threshold, then an edge is present at that pixel, and the direction with the smallest 1-D variance is considered as the edge direction of the pixel. Utilizing a

filter 160, at "no direction" pixels, a 2-D average filter is applied. At a pixel with a detected edge direction, a 1-D average filter is applied along the detected direction. By filtering along image edge directions, the directional

5 filter 100 is able to retain most of the image structures while reducing the noise level of the input image.

There are two major shortcomings to the directional filtering technique. The first is that the threshold value

10 must be manually tuned and usually it is difficult to select the right value. An improperly selected threshold value will cause either image blurring or insufficient noise reduction. The second shortcoming of the directional filter is that the filter strength is fixed. That means a

15 relatively clean image is processed the same way as a highly noisy image. This causes the relatively clean image to unnecessarily lose some fine structures and be degraded.

Brief Summary of the Invention

20 The present invention addresses the above shortcomings. As such, in one embodiment the present invention provides a global and local statistics controlled noise reduction system wherein the video image noise reduction processing is effectively adaptive to both image

local structure and global noise level. And, a noise estimation method according to the present invention provides reliable global noise statistics to the noise reduction system.

5

Such a global and local statistics controlled noise reduction system dynamically/adaptively configures a local filter for processing each image pixel, and processes the pixel with that local filter. The filtering process of the

10 noise reduction system is controlled by both global and local image statistics that are also computed by the system. In one example, the local statistics computed by the system are 1-D and 2-D local variances, and the global statistics computed by the system is the global noise

15 standard deviation. The local filter configured by the system for each image pixel has different filtering directions and variable strength for different pixels. The direction of the local filter is determined by 1-D local variances. The strength of the local filter is computed

20 directly from the local variances and the global noise standard deviation.

According to a further aspect of the present invention, the global noise standard deviation is estimated

by a noise estimation method. First, the image is divided into overlapping or non-overlapping blocks, and the mean and the standard deviation of each block are calculated. Then, the smallest standard deviation is found together

5   with the corresponding block mean. After the smallest standard deviation and its corresponding mean have been found, a "saturation checking" process is applied to determine whether the block with the smallest standard deviation has saturated. This determination is based on

10   the relation between the smallest standard deviation and its corresponding mean.

If saturation is not detected, the calculated block standard deviations that are within a neighboring interval

15   centered at the smallest standard deviation are averaged, and the average value is taken as the estimated global noise standard deviation. The radius of the neighboring interval depends on the value of the smallest standard deviation.

20

If saturation is detected, first a saturation compensation term is added to the smallest standard deviation to generate a compensated smallest standard deviation. The saturation compensation term is computed

from the smallest standard deviation and its corresponding

mean. Then, the calculated block standard deviations that

are within a neighboring interval centered at the

compensated smallest standard deviation are averaged to

5   obtain the estimated global noise standard deviation. The

noise standard deviation is used in the noise reduction

system.

Other objects, features and advantages of the present

10   invention will be apparent from the following specification

taken in conjunction with the following drawings.

Brief Description of the Drawings

FIG. 1 shows a block diagram of a prior art

15   directional filter;

FIG. 2 shows a functional block diagram of an

embodiment of a global and local statistics controlled

noise reduction system according to the present invention;

FIG. 3 illustrates example directions for computing

20   the 1-D variances in the system of FIG. 2;

FIG. 4 shows an example curve representing dependency

of the filter strength on local variance and global noise

standard deviation;

FIG. 5 shows a function block diagram of an embodiment of a noise estimation system utilized for the global statistics computing unit of FIG. 2; and

FIGS. 6A and 6B show example diagrams illustrating the
5   effect of pixel values driven into saturation (0 or 255) by noise.

Detailed Description of the Invention

As noted above, in one embodiment the present invention provides a global and local statistics controlled
10   noise reduction system wherein the video image noise reduction processing is effectively adaptive to both image local structure and global noise level. And, a noise estimation method according to the present invention provides reliable global noise statistics to a noise
15   reduction system. The system dynamically configures a local filter for processing each image pixel, and processes the pixel with that local filter. The filtering process is controlled by both global and local image statistics. In one example, the local statistics computed by the system
20   are 1-D and 2-D local variances, and the global statistics computed by the system is the global noise standard deviation. The dynamically configured local filter has different directions and variable strength for different

pixels. The direction of the local filter is determined by
1-D local variances. The strength of the local filter is
computed directly from the local variances and the global
noise standard deviation.

5

The global noise standard deviation is estimated by a
preferred noise estimation method that comprises the
following steps. First, the image is divided into
overlapping or non-overlapping blocks, and the mean and the

10 standard deviation of each block are calculated. Then, the
smallest standard deviation is found together with the
corresponding block mean. After the smallest standard
deviation and its corresponding mean have been found, a
"saturation checking" process is applied to determine

15 whether the block with the smallest standard deviation has
saturated. The process is based on the relation between
the smallest standard deviation and its corresponding mean.

If no saturation is detected, the calculated block

20 standard deviations that are within a neighboring interval
centered at the smallest standard deviation are averaged,
and the average value is taken as the estimated global
noise standard deviation. The radius of the neighboring
interval depends on the value of the smallest standard

deviation. If saturation is detected, first a saturation compensation term is added to the smallest standard deviation to generate a compensated smallest standard deviation. The saturation compensation term is computed

5   from the smallest standard deviation and its corresponding mean. Then, the calculated block standard deviations that are within a neighboring interval centered at the compensated smallest standard deviation are averaged to obtain the estimated global noise standard deviation (the

10   radius of the neighboring interval depends on the value of the compensated smallest standard deviation). The global noise standard deviation is used in the noise reduction system.

15   An example of the noise reduction system according to the present invention is now described. FIG. 2 shows a functional block diagram of the example global and local statistics controlled noise reduction system 200 according to an embodiment of the present invention. The system 200

20   comprises a Global Statistics unit 210, a Local Statistics unit 220, a Direction Detector 230, a Filter Generator 240, and a Pixel Filtering unit 250. A digital video input image is first supplied to both the Global Statistics unit 210 and the Local Statistics unit 220. The Global

Statistics unit 210 estimates the global noise statistics

using said noise estimation method (also described further

below). The output of the Global Statistics unit 210 is

the global noise standard deviation σ, which is supplied to

5 the Filter Generator 240. The Local Statistics unit 220

computes the 2-D local variance within a small window

centered at the current pixel and the 1-D local variances

along four directions within the same window.

10 FIG. 3 illustrates an example two-dimensional window

300 including nine image pixels 310, and example directions

for computing the 1-D local variances for pixel (i,j), where

i and j are the indices for pixel row and column,

respectively. The designations L_1, L_2, L_3 and L_4 denote the

15 horizontal, vertical, diagonal from upper left to lower

right, and diagonal from upper right to lower left

directions, respectively. Further, the designation σ_k^2

denotes the 1-D local variance computed for direction L_k,

wherein $k = 1$, 2, 3 or 4. And, the designation σ_0^2 denotes

20 the 2-D local variance.

In the example of FIG. 3, $P(i,j)$ denotes e.g. the image

gray-scale value of the pixel at position (i,j), wherein the

local variances σ_k^2 (k = 0, 1, 2, 3, 4) at pixel (i,j) are

computed within the 3x3 window 300 by example as follows.

If k = 0, then σ_0^2 is the 2-D variance, and is computed

5   by:

$$\sigma_0^2 = (\sum_{s=-1}^{1}\sum_{t=-1}^{1}(P(i+s,j+t)-\mu_0)^2)/9 ,$$

where μ_0 is the corresponding 2-D mean, defined as:

$$\mu_0 = (\sum_{s=-1}^{1}\sum_{t=-1}^{1}P(i+s,j+t))/9 .$$

10   If k > 0, then σ_k^2 (k = 1, 2, 3, 4) are 1-D variances

along the direction L_k (k = 1, 2, 3, 4), and are

computed by:

$$\sigma_1^2 = ((P(i,j-1)-\mu_1)^2 + (P(i,j)-\mu_1)^2 + (P(i,j+1)-\mu_1)^2)/3 ;$$

$$\sigma_2^2 = ((P(i-1,j)-\mu_2)^2 + (P(i,j)-\mu_2)^2 + (P(i+1,j)-\mu_2)^2)/3 ;$$

15       $$\sigma_3^2 = ((P(i-1,j-1)-\mu_3)^2 + (P(i,j)-\mu_3)^2 + (P(i+1,j+1)-\mu_3)^2)/3 ;$$

$$\sigma_4^2 = ((P(i-1,j+1)-\mu_4)^2 + (P(i,j)-\mu_4)^2 + (P(i+1,j-1)-\mu_4)^2)/3 ;$$

where μ_k (k = 1, 2, 3, 4) are the means along the

direction L_k (k = 1, 2, 3, 4), and are computed by:

$$\mu_1 = (P(i,j-1)+P(i,j)+P(i,j+1))/3 ;$$

20       $$\mu_2 = (P(i-1,j)+P(i,j)+P(i+1,j))/3 ;$$

$$\mu_3 = (P(i-1, j-1) + P(i, j) + P(i+1, j+1))/3 \, ;$$

$$\mu_4 = (P(i-1, j+1) + P(i, j) + P(i+1, j-1))/3 \, .$$

After computing the local variances, the Local

5 Statistics unit 220 (FIG. 2) provides the 1-D local

variances to the Direction Detector 230 to determine the

local edge direction. The Direction Detector 230 then

selects the direction that has the smallest 1-D variance as

the local edge direction, and provides it to the Filter

10 Generator 240. The Local Statistics unit 220 also provides

the computed 1-D and 2-D local variances to the Filter

Generator 240, to generate/configure a local filter based

on the statistics quantities provided by both the Local

Statistics unit 220 and the Global Statistics unit 210.

15

The Filter Generator 240 generates a local filter for

the pixel to be filtered. The direction of the local

filter is the local edge direction detected by the

Direction Detector 230. The strength of the local filter

20 is computed by using the global noise standard deviation

σ provided by the Global Statistics unit 210 and the local

variances σ_k^2 (k = 0, 1, 2, 3, 4) provided by the Local

Statistics unit 220. For edge direction L_k (k = 1, 2, 3,

4), the designation α_k (k = 1, 2, 3, 4) denotes the corresponding filter strength along those directions. Further, the designation α_0 denotes the filter strength for non-edge area filtering. While α_k (k = 1, 2, 3, 4) controls the strength for filtering along the edge direction, α_0 controls the strength for non-edge area filtering.

The filter strengths α_k (k = 1, 2, 3, 4) for edge direction L_k (k = 1, 2, 3, 4) are functions of the global noise standard deviation and the local variance, and are computed in one example as:

$$\alpha_k = \min(2\sigma, \max(3\sigma - \sigma_k, 0))/(2\sigma) ;$$

wherein $\min(a,b)$ is the minimal function that returns the smaller one of the two values a and b, and $\max(a,b)$ is the maximal function that returns the larger one of the two values a and b.

FIG. 4 shows an example curve/plot 400 of the filter strength function α_k. When σ_k (i.e., the square root of the local variance) is small in comparison with the global noise standard deviation σ (indicating that the local change is caused by noise), the local filter has full

strength. When σ_k is large in comparison to σ (indicating that the local change along the detected direction is caused by image structure), the local filter has zero strength. In between, the local filter strength

5 continuously varies with σ_k. Further, the filter strength α_k varies with the global noise standard deviation σ (i.e., it increases as the global noise standard deviation increases).

10 The filter strength α_0 for non-edge area is computed similarly as following:

$$\alpha_0 = \min(2\sigma, \max(3\sigma - \sigma_0, 0))/(2\sigma) .$$

The curve for α_0 is similar to that for α_k ($k = 1, 2, 3,$ or 4) shown in FIG. 4.

15 Using the detected local edge direction L_k ($k = 1, 2, 3,$ or 4), the edge direction filter strengths α_k ($k = 1, 2, 3,$ or 4), and the non-edge area filter strength α_0 computed above, the Filter Generator unit 240 (FIG. 2) generates/configures the local filter f_k ($k = 1, 2, 3,$ or 4)

20 as follows.

If the detected direction is L₁, then f_1 is a 2-D local filter for horizontal direction, and is defined as:

$$f_1 = \frac{1}{9}\begin{bmatrix} \alpha_0 & \alpha_0 & \alpha_0 \\ \alpha_0 + 3\alpha_1(1-\alpha_0) & \alpha_0 + 3(3-2\alpha_1)(1-\alpha_0) & \alpha_0 + 3\alpha_1(1-\alpha_0) \\ \alpha_0 & \alpha_0 & \alpha_0 \end{bmatrix};$$

5   If the detected direction is L₂, then f_2 is a 2-D local filter for vertical direction, and is defined as:

$$f_2 = \frac{1}{9}\begin{bmatrix} \alpha_0 & \alpha_0 + 3\alpha_2(1-\alpha_0) & \alpha_0 \\ \alpha_0 & \alpha_0 + 3(3-2\alpha_2)(1-\alpha_0) & \alpha_0 \\ \alpha_0 & \alpha_0 + 3\alpha_2(1-\alpha_0) & \alpha_0 \end{bmatrix};$$

If the detected direction is L₃, then f_3 is a 2-D local

10   filter for the diagonal direction from upper left to lower right, and is defined as:

$$f_3 = \frac{1}{9}\begin{bmatrix} \alpha_0 + 3\alpha_3(1-\alpha_0) & \alpha_0 & \alpha_0 \\ \alpha_0 & \alpha_0 + 3(3-2\alpha_3)(1-\alpha_0) & \alpha_0 \\ \alpha_0 & \alpha_0 & \alpha_0 + 3\alpha_3(1-\alpha_0) \end{bmatrix};$$

and

15   If the detected direction is L₄, then f_4 is a 2-D local filter for the diagonal direction from upper right to lower left, and is defined as:

$$f_4 = \frac{1}{9}\begin{bmatrix} \alpha_0 & \alpha_0 & \alpha_0 + 3\alpha_4(1-\alpha_0) \\ \alpha_0 & \alpha_0 + 3(3-2\alpha_4)(1-\alpha_0) & \alpha_0 \\ \alpha_0 + 3\alpha_4(1-\alpha_0) & \alpha_0 & \alpha_0 \end{bmatrix}.$$

The generated local filter f_k is supplied to the Pixel

Filtering unit 250 (FIG. 2). The pixel is then filtered

using the weighted sum of its neighboring pixels within a

e.g. 3×3 window with the corresponding filter coefficients

as the weights.

As noted, the Global Statistics unit 210 estimates the

global noise statistics using a preferred noise estimation

method. Different methods have been proposed to estimate

the noise present in the images, such as those described in

the paper by S. I. Olsen: "Noise Variance Estimation in

Images: An Evaluation", Graphical Models and Image

Processing, vol. 55, no. 4, pp. 319-323, 1993.

However, existing methods have not properly considered

saturation effects (i.e., pixel values driven into

saturation (0 or 255) by the noise, causing inaccurate

estimates (in most cases underestimates) of noise).

Inaccurate noise estimate can have serious impact on the

performance of the noise reduction system that is

controlled by global noise statistics.

5   FIG. 5 shows a functional block diagram of an example

noise estimation system 500 according to the present

invention, for the Global Statistics Computing unit 210 of

FIG. 2. The example noise estimation system 500 according

to the present invention is capable of handling said

saturation effect and providing accurate noise estimates.

10   The input image is first divided into overlapping or non-

overlapping blocks B_n of size $H \times W$; $(n = 1, 2, \ldots, N)$; where

N is the total number of blocks, and the mean and the

standard deviation of each block are computed by the Mean

and Standard Deviation Calculator unit 510. The selected

15   block size should not be too small to ensure a robust

estimate. Preferably, the block size is e.g. 7×7 or 5×9

pixels (other block sizes can be used). The mean m_n and the

standard deviation d_n of block B_n are computed in the unit

510, respectively, as:

20

$$m_n = \frac{\sum_{(i,j) \in B_n} P(i,j)}{H \times W};$$

$$d_n = \sqrt{\frac{\sum_{(i,j) \in B_n} (P(i,j) - m_n)^2}{H \times W}}.$$

The computed block standard deviations and means are then provided to a Minimal Finder 520. The block standard deviations are also provided to a Selective Averaging unit 530.

5

The Minimal Finder 520 finds the smallest standard deviation, and records the smallest standard deviation and its corresponding block mean as d_0 and m_0, respectively, wherein the values d_0 and m_0 are then supplied to a

10 Saturation Checker 540.

The Saturation Checker 540 checks whether saturation has occurred in the block with the smallest standard deviation d_0. That is, the Saturation Block checker

15 determines/detects if pixel values in the block are driven into saturation (e.g., 0 or 255) due to noise, which may cause inaccurate estimates of image noise. If saturation has occurred, a Saturation Compensator 550 compensates for d_0.

20

Examples of saturation detection criteria and the compensation methods are provided below in conjunction with FIGS. 6A-6B which illustrate examples of the effect of

pixel values driven into saturation by noise (e.g., pixel value is at a lower limit such as 0 or at an upper limit such as 255).

5   For this example an upper limit $UL = 255$, a lower limit $LL = 0$ and a mid value $M = 128$. Such that, if $m_0 < 128$ and $d_0 > m_0 - 0$, then saturation is detected at the lower limit 0 (FIG. 6A). In this case d_0 is compensated as $\widetilde{d}_0 = d_0 + K \cdot (d_0 - (m_0 - 0))$, wherein $\widetilde{d}_0$ denotes

10 the compensated smallest standard deviation;

If $m_0 \geq 128$ and $d_0 > 255 - m_0$, then saturation is detected at the upper limit 255 (FIG. 6B). In this case d_0 is compensated as $\widetilde{d}_0 = d_0 + K \cdot (d_0 - (255 - m_0))$;

Otherwise, no saturation is detected. In this case no

15 compensation is needed for d_0, therefore $\widetilde{d}_0 = d_0$.

In the above expressions for $\widetilde{d}_0$, the compensation parameter K is empirically determined. Preferably in this example $K = 5.0$ is used. As those skilled in the art will

20 recognize, the saturation detection method can be easily generalized to other situations where the images are

represented by different bit values and therefore have different values for *UL*, *LL* and *M*.

The compensated smallest standard deviation $\widetilde{d}_0$ is then

5   supplied to the Selective Averaging unit 530 (FIG. 5) to generate the final estimate of the global noise standard deviation σ, utilized in the system 200 of FIG. 2.

The Selective Averaging unit 530 (FIG. 5) first

10   selects those block standard deviations (provided by the Mean and Standard Deviation Calculator 510) that are within a selected range of (e.g., close to) the compensated smallest standard deviation $\widetilde{d}_0$. In one example, a block standard deviation d_n *(n = 1,2,...,N)* is considered within

15   a range of $\widetilde{d}_0$ if $|d_n - \widetilde{d}_0| < \max(\widetilde{d}_0,1)$. The selected block standard deviations are then averaged, and the average value is taken as the final estimate of the global noise standard deviation σ, for use in the system 200 (FIG. 2).

20   While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of the invention with the understanding that the present

disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated. The aforementioned systems 200 and 500

5 according to the present invention can be implemented in many ways, such as program instructions for execution by a processor, as logic circuits, as ASIC, as firmware, etc., as is known to those skilled in the art. Therefore, the present invention is not limited to the example embodiments

10 described herein.

The present invention has been described in considerable detail with reference to certain preferred versions thereof; however, other versions are possible.

15 Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.